Graphing

"One must learn by doing the thing; though you think you know it, you have no certainty until you try."

Sophocles

GENERAL PRINCIPLES

Graphs are frequently used to present and analyze data in science, engineering and business. Regardless of the purpose of a given graph, there exist several "rules" of plotting that lead to clear, useful graphs. Some of them are summarized here, and more detail can be found under the appropriate headings at http://www.owlnet.rice.edu/~labgroup/.

1. A graph should be labeled so that its meaning is clear. The quantity plotted along each axis should be indicated, along with the units in which the plotted data are expressed. An appropriate title should also be on the page.
2. Scales should be chosen for ease of use. This is best accomplished by choosing one division equal to a multiple of 1, 2, 5, or 10. The scales used on the two axes need not be the same, but should be chosen so that the data fill the page. It is not essential to have the point (0,0) on the graph.
3. Experimental points should be plotted with a small dot, cross, etc. A circle can then be drawn around the point to better show its position.
4. The data are fitted by drawing a smooth curve through the experimental points. Because the world is not perfect, the curve may not pass through all the points, but it should be close.

Figure 1 is a simple graph which illustrates these rules.

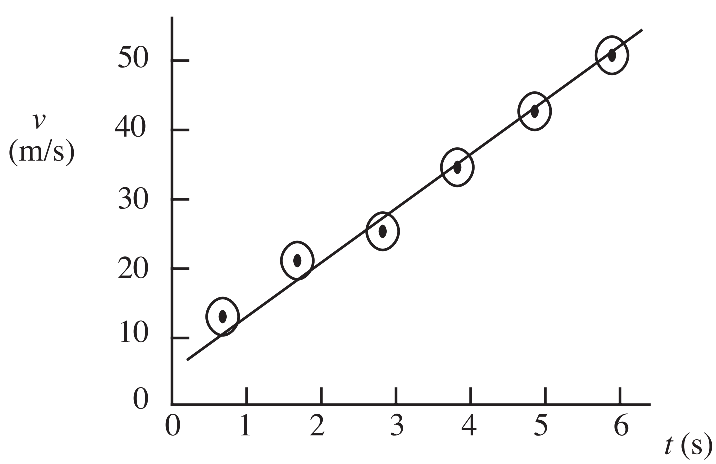

Fig. 1. Example of a properly drawn graph showing velocity vs time for an object in free fall. The solid line is the best fit to the data.

ANALYSIS WITH GRAPHS

For many purposes a graph is used only to provide a compact display of data. We will usually want to take an additional step, and use the graph to quantitatively analyze the data. In the example, the data seem to lie on a straight line. If we had a theory which predicted a linear relation, we could conclude that these data are consistent with the theory. Even without a theory, we could conclude that $v = v_o + at$, and that $v = v_o + bt^2$ is probably not correct.

The equation of a straight line can be written as $v = v_o + at$ when v is plotted vertically and t horizontally. The constant a is the slope of the line, and v_o is the value of v when $t = 0$ (the "intercept"). The values of slope and intercept are easily found from the plot by drawing in the straight line that seems to pass closest to the data points, and then finding the parameters of that line. Alternatively, the graphing software on the lab computers will do the same thing if you invoke the linear curve fit. With either method, you are using all the available information to deduce the slope and intercept, which is far preferable to using two arbitrarily chosen data points for the computation.

Be aware that when plotting data with units, both the slope and the intercept have units also. Since the slope is a ratio of the quantity plotted vertically to the quantity plotted horizontally, it has the units of that ratio. The intercept has the same units as the quantity plotted vertically. In the example of Fig. 1, the slope is measured in m/sec^2 and the intercept in m/sec.

You can estimate the uncertainty in the slope and intercept by drawing other lines that are plausible but at the outer limits of the scatter in the data, and computing their slopes and intercepts. If you use the graphing software it will automatically display uncertainties, but tends to underestimate them.

When the measurements are not expected to follow a linear relationship, the analysis can follow one of two possible approaches. The simplest is to linearize the relationship by a clever change of variable. Alternatively, one can use specialized software to find the parameters of an assumed function that gives the best description of the observations.

As an example of the linearization approach, suppose we measure two quantities, y and x, which are actually related by $y = a + bx^2$. A plot of y vs x will be a curve, and it might be hard to decide by examination whether or not the data actually follow the quadratic. However, a plot of y vs x^2 will be a straight line with slope b and intercept a, and it is quite easy to see how closely the data follow the presumed line. A more complicated example is a measurement of position, s, as a function of time for uniform acceleration. Theory predicts the relation $s = v_ot + 1/2\ at^2$. If we divide both sides by t we obtain $s/t = v_o + 1/2\ at$. A plot of s/t vs t should be a straight line, and we can quickly decide if the theory is correct.

The graphing software available on the lab computers will allow you to choose a function that you think describes your data and find the values of the adjustable parameters that lead to the best approximation. In the second example above, we could plot s vs t, and then ask the program to find the values of a and b in the expression $s = at + bt^2$ that give the closest agreement with the data. The numerical values of a and b would then be converted to physically meaningful parameters by comparison with the original equation.

It should be obvious at this point that graphical data analysis is something of an art. Intuition, theory and experience all provide useful guides, but each situation must be examined carefully. You will have considerable opportunity to study this art during the weeks ahead.